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TRANSACTIONS.

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No. 804.

THE COMPRESSIBILITY OF SALT MARSH UNDER THE WEIGHT OF EARTH FILL.

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PRESENTED MARCH 17TH, 1897.

WITH DISCUSSION.

The importance of the dredging interests in and about the great cities of the sea coast cannot easily be overestimated; the very existence of the harbors and channels through which intercourse with the outside world is carried on, as well as the locations of piers and warehouses for the convenience of this intercourse, is often dependent upon the efficiency of the dredge. The methods formerly employed were comparatively expensive, and the work was confined to the improvement of the more necessary channels and the filling for the more important docks, warehouses and railroad terminals where the great business transactions warranted large outlays of money.

The present reduced cost of dredging due to the introduction of hydraulic methods makes practicable many plans of real estate development, which up to the time of these improvements could not be considered because of the prohibitory cost. Among these projected plans is the reclamation of tracts of marsh or meadow land bordering the salt water creeks and bays in the vicinity of cities and large towns.

The extent of such marsh land which might be made valuable for both business and residential purposes in the vicinity of New York may be appreciated when it is considered that within a radius of 15 miles of the City Hall the area of such land is three times as great as that of Manhattan Island.

The growth of the cities and the increasing demand for summer homes, together with the reductions in the cost of dredging, open an important and comparatively new field for both the engineer and contractor in the reclamation of these lands, not only about New York, but near every large center of population on the Atlantic seaboard. From the standpoint of the engineer one question of interest in an investigation or report on such a proposed work is the compressibility of the marsh under the weight of the requisite filling material.

During the fall of 1894 an opportunity was afforded for obtaining information on this question; the author was called upon to prepare a specification and solicit bids for the reclamation of 80 acres of such marsh land on the north shore of the Great South Bay, opposite Fire Island Light, at Islip, Suffolk County, N. Y. The underlying material is sand and gravel, with occasionally a little clay, the surface of which slopes gradually from the lower edge of the adjacent upland to the bay. This marsh, locally known as "meadow," consists of a growth of various salt grasses on the surface of the mud just above the level of ordinary high tide. This mud is the accumulation of decayed seaweed and other vegetable matter, and, owing to its composition and location, is soft and compressible. The surface of this meadow sod is, so far as the author's experience and observation goes, practically level and just above ordinary high tide, 0.4 ft. in this case. This sod growth forms a kind of leathery covering over the mud, distributing the pressure due to the weight of the filling material above upon the mud below, and preventing it from breaking through and being replaced by the heavier sand. The pressure on the mud from the fill above tends to increase the consistency of the mud by squeezing out the water until a condition of equilibrium is reached. It is a matter of conjecture whether the water rises through the sand and adjacent meadow to the surface and is dried out by the air or oozes horizontally out to the bay and creek; probably it does both.

The average thickness of the meadow sod and mud is 4.3 ft., the maximum thickness being 9.5 ft.; the ordinary rise and fall of tide is 15 ins.

The specification called for a fill of earth to a height of 3 ft. above the original level of the meadow surface, the contractor to assume the responsibility for the compression of the meadow sod up to the date of completion of the total work. As the contract price was per acre of finished fill without regard to the compression of the meadow, the investigation as to the compression would have no bearing on this undertaking, but the opportunity for an examination of the matter was too favorable to be neglected.

The total area to be filled was divided into squares of 100 ft. At each corner a stake was driven through the meadow firmly into the underlying sand and gravel, and the top was sawed off at the 3-ft. grade level. A board about 1 ft. square, with a short stake nailed to one edge, was placed on the meadow surface at the side of each grade stake, the short stake being pushed into the meadow sod so that the board could remain where placed at the surface and not be washed out of position as the filling took place. The thickness of the meadow sod was ascertained by pushing down a half-inch iron rod to the sand, and the thickness of the filled material from the surface down to the board was similarly determined. By referring all elevations to the top of the grade stake, the amount of compression was readily ascertained. The whole area includes all kinds of meadow, from hard to soft, so that the result may fairly be considered as representative of meadow where the rise and fall of the tide does not differ materially from that stated.

The contract was awarded to a firm which used one hydraulic dredge, equipped with an 18-in. centrifugal pump, which was run at a maximum speed of 250 revolutions per minute. The suction and discharge were also 18 ins. in diameter. The filling material was almost entirely sand from the bay and from canals dug through the meadow; the sand was a very sharp quartz, which caused serious wear on the pump, which was finally obviated by the use of hardened steel linings. These protected the pump shell and could be readily replaced as they became worn. The weight of the filling material (sand) varies from 2 875 lbs. to 2 956 lbs. dry and from 3 037 lbs. to 3 118 lbs. wet per cubic yard, the wet sand being about $5\frac{1}{2}\%$ heavier than the dry.

In the accompanying tables the percentages given are with reference to the thickness of the meadow, and where a percentage is noted, in order that its proper value may be apparent, the number of observations of which it is the average is noted. A subdivision as to thick-

ness is also made into five classes as follows: 1.5 to 3.5 ft. inclusive; 3.6 to 4.5 ft. inclusive; 4.6 to 5.5 ft. inclusive; 5.6 to 6.5 ft. inclusive, and 6.6 ft. and upward, so that any peculiarity due to different thicknesses might be disclosed. It is also proper to state that the averages are carried out to tenths of 1% in order that any ratio or tendency shown by the results might be more easily noted and studied, rather than with any idea of determining the actual compression with mathematical exactness to a fraction of an inch.

TABLE No. 1.—PERCENTAGES OF COMPRESSION FOR VARIOUS PERIODS AND DEPTHS OF MEADOW.

Duration of Time.	PERCENTAGE OF COMPRESSION AND NUMBER OF STATIONS OBSERVED, FOR THICKNESS OF MEADOW SOD AS SHOWN BELOW.											
	1.5 to 3.5 ft. Av., 2.7 ft.		3.6 to 4.5 ft. Av., 4 ft.		4.6 to 5.5 ft. Av., 5 ft.		5.6 to 6.5 ft. Av., 5.9 ft.		Over 6.5 ft. Av., 7.9 ft.		For all thicknesses combined.	
	Per-cent.	No. sta.	Per-cent.	No. sta.	Per-cent.	No. sta.	Per-cent.	No sta.	Per-cent	No. sta.	Per-cent.	No. sta.
1 mo....	7.7	49	10.6	47	11.7	37	10.0	20	10.9	19	10.0	172
2 mos...	10.1	49	14.2	47	14.8	37	12.8	20	14.8	19	13.1	172
3 mos...	11.8	48	15.0	43	16.4	36	12.8	17	16.5	19	14.3	163
4 mos...	12.3	47	16.0	43	17.1	36	13.8	17	17.5	19	15.1	162
5 mos...	12.5	47	16.4	43	17.6	36	14.4	17	18.2	19	15.5	162
6 mos...	12.9	45	16.9	39	18.1	34	14.0	11	18.6	19	15.9	148
7 mos...	13.5	43	17.4	36	19.4	28	15.7	9	19.4	19	16.7	135
8 mos...	13.1	39	17.7	27	20.2	25	17.4	7	20.1	15	16.9	113
9 mos...	12.6	36	17.9	22	19.7	17	17.7	7	20.7	14	16.6	96
10 mos...	10.9	32	17.0	19	20.0	12	18.3	6	21.6	13	16.2	82
11 mos...	11.1	25	17.8	13	20.8	10	24.0	2	22.0	13	16.7	63
12 mos...	11.1	21	20.5	4	22.3	6	26.0	1	27.6	6	16.9	38

TABLE No. 2.—DISTRIBUTION OF THE TOTAL PERCENTAGE OF COMPRESSION THROUGHOUT THE SUCCESSIVE MONTHS, FOR ALL THICKNESSES COMBINED.

No. of stations.	Total percentage of compr.	1st mo.	2d mo.	3d mo.	4th mo.	5th mo.	6th mo.	7th mo.	8th mo.	9th mo.	10th mo.	11th mo.	12th mo.
12....	22.4	10.2	5.0	2.8	1.0	1.0	0.7	0.1	0.6	0.1	0.4	0.3	0.2
34....	16.5	7.9	3.3	2.1	0.7	0.2	0.6	0.7	0.0	0.2	0.4	0.3	0.1
38....	16.9	8.3	3.4	2.2	0.5	0.3	0.5	0.3	0.3	0.4	0.3	0.1	0.3
63....	16.7	8.3	4.0	1.4	0.6	0.3	0.4	0.4	0.3	0.3	0.3	0.4	.....
82....	16.2	8.0	3.6	1.5	0.9	0.2	0.7	0.3	0.3	0.3	0.4	.....	.....
96....	16.6	9.0	3.3	1.6	0.8	0.3	0.5	0.4	0.3	0.4	.....	.....	.....
113....	16.9	9.7	3.3	1.5	0.8	0.3	0.5	0.4	0.4	.....	.....	.....	.....
135....	16.7	9.7	3.2	1.3	0.8	0.4	0.7	0.6	.....	.....	.....	.....	.....
148....	15.9	9.6	3.2	1.3	0.8	0.3	0.7	.....	.....	.....	.....	.....	.....
162....	15.5	9.8	3.1	1.3	0.9	0.4	.....	.....	.....	.....	.....	.....	.....
162....	15.1	9.8	3.1	1.3	0.9	.....	.....	.....	.....	.....	.....	.....	.....
163....	14.3	9.8	3.1	1.4	.....	.....	.....	.....	.....	.....	.....	.....	.....
172....	13.1	10.0	3.1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE No. 3.—COMPARISON OF AVERAGE COMPRESSION WITH COMPRESSION FOR THIN, MEDIUM AND THICK, MEADOW.

Duration of Time.	General Average. See Table No 1.		Thin Meadow. 1.5 to 3.5 Ft. inclusive. Average Thickness = 2.7 Ft.			Medium Meadow. 3.6 to 6.5 Ft. inclusive. Average Thickness = 4.7 Ft.			Thick Meadow. 6.6 Ft. and Upward. Average Thickness = 7.9 Ft.		
	Number station.	Percentage.	Number station.	Percentage.	Variation from general average.	Number station.	Percentage.	Variation from general average.	Number station.	Percentage.	Variation from general average.
1 mo....	172	10.0	49	7.7	— 2.3	104	1C.9	+ 0.9	19	10.9	+ 0.9
2 mos...	172	13.1	49	10.1	— 3.0	104	14.1	+ 1.0	19	14.8	+ 1.7
3 mos...	163	14.3	48	11.8	— 2.5	96	15.1	+ 0.8	19	16.5	+ 2.2
4 mos...	162	15.1	47	12.3	— 2.8	96	16 0	+ 0.9	19	17.5	+ 2.4
5 mos...	162	15.5	47	12.5	— 3.0	96	16.5	+ 1.0	19	18.2	+ 2.7
6 mos...	148	15.9	45	12 9	— 3.0	84	17.0	+ 1.1	19	18.6	+ 2.7
7 mos...	135	16.7	43	13.5	— 3.2	73	17.9	+ 1.2	19	19.4	+ 2.7
8 mos...	113	16.9	39	13.1	— 3.8	59	18.7	+ 1.8	15	20.1	+ 3.2
9 mos...	96	16.6	36	12.6	— 4.0	46	18.5	+ 1.9	14	20 7	+ 4.1
10 mos...	82	16.2	32	10.9	— 5.3	37	18.4	+ 2.2	13	21.6	+ 5.4
11 mos...	63	16.7	25	11.1	— 5.6	25	19.5	+ 2.8	13	22.0	+ 5.3

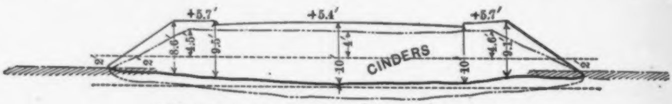
NOTE—In taking the average percentage of compression for all thicknesses, it is assumed that it is independent of the thickness of the meadow. This is not strictly correct, the percentage of compression for thin meadow being less than, and for thick meadow more than, for the general average as shown above for all thicknesses.

Some experience of the author in Jamaica Bay during 1896 on the same kind of work shows the percentage of compression to be materially less where the rise and fall of the tide is greater (4 to 6 ft. in Jamaica Bay), other things being equal. The information there obtained was not sufficiently extensive to authoritatively warrant any more definite statement than this; the same relative level, practically, is maintained between the surface of the meadow and ordinary high tide, and it is suggested that the opportunity for drying out of the upper portion of the meadow sod during a part of each tide tends to harden the sod, and make it less compressible than where it is saturated all the time.

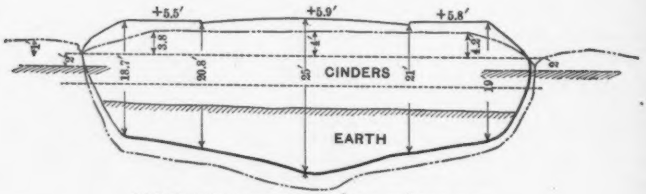
DISCUSSION.

Mr. McCann.

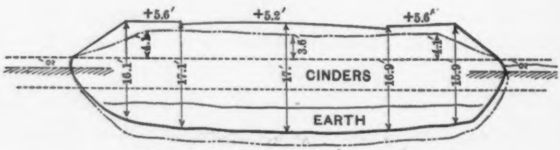
THOMAS H. McCANN, M. Am. Soc. C. E.—Between the original island of Hoboken, N. J., and the mainland there was at one time a branch of the Hudson River, which has been gradually filled up until its bed is now covered by a salt marsh with its surface about 2 ft. below the average high-water level. The depth of this marsh ranges from 30 to 100 ft., being generally greatest near the mainland. The material is a dark blue clay overlaid with silt and decayed vegetable matter. The numerous street improvements constructed over this marsh furnish some information of the same nature as that given in the paper. The



UNDERLYING MATERIAL; 56′ SILT, 10′ SAND, ROCK.
FIG. 1



UNDERLYING MATERIAL; 54′ SILT, 17′ SAND, ROCK.
FIG. 2



UNDERLYING MATERIAL; 61′ SILT, 17′ SAND.
FIG. 3

filling was done by contract at a fixed price per cubic yard, the quantity of material, usually boiler-house cinders, being ascertained by measurement on the scows and again by making borings and cross-sections of the streets. There was a difference of about 15% between the two measurements, which represents the shrinkage of the filling in the bank.

Three typical sections of one of these streets are presented in Figs. 1 to 3. The upper and lower dotted lines are the levels of high and low water respectively, the distance between them being about 5 ft.

The surface elevation of the original meadow is indicated by the shaded line, and is 2 ft. below mean high water. The solid line gives a section of the new embankment as determined by borings, while the broken line shows the amount of settlement after three years. There is little displacement of the meadow at the sides of the fill where the latter is not more than 10 or 12 ft. deep, but where it reaches greater depths, the meadow is forced up. The street surface is generally 4 to 5 ft. above mean high water. At the point where the section in Fig. 2 was taken the embankment has settled about 2 ft., while the meadow has risen. Mr. McCann.

The streets were generally made by building a roadway in the center, and then widening the bank gradually to its full width, about 65 ft. This method of construction accounts, to some extent, for the greater depth of the fill in the center than toward the sides. There was no filling on the meadow alongside the bank. Fig. 2 is a section at a point where the first filling was done with earth from some cellars the contractor was digging. The street had about 10 ft. of this material on it when it sank suddenly 2 or 3 ft. during one night. The remainder of the fill was made with cinders. This section is among the deepest on the work.

It is well known that in filling a bank on marsh land three things occur: First, there is a compression and displacement of the lighter and softer marsh by the heavier filling; second, a shrinkage of the filling material and about the time the road is finished the embankment is floating, so to speak, on the marsh; third, the embankment settles gradually, compressing or displacing (in many cases doing both) the softer marsh. This settlement continues for many years, and, of course, is greatest in a road on which there is heavy traffic.

There seems to be no constant relation between the depth of the marsh and that of the filling. In hundreds of cross-sections of filling on marsh lands taken during the last thirty years, the speaker found the percentage between these depths to vary from 10 to 70. The three sections presented are from one street, and are within a few hundred feet of each other.

CORRESPONDENCE.

Mr. Clark. J. H. CLARK, Assoc. M. Am. Soc. C. E.—In 1891–92, the writer was engaged at South Bend, Wash., on filling a tidal meadow for the Northern Pacific Railroad Company. About 160 acres were filled to a height of 3 ft. and 20 acres to a height of 5 ft., with sand excavated from the river. It was proposed to measure the settlement of the original surface by a method similar to that of the author, but there was no settlement up to the spring of 1893, when the writer left the work. Both bench and reference marks were carefully set. The average range of the tide at South Bend is from 6 to 8 ft., with a maximum of 16 to 18 ft. The meadow was composed of silt, resting on clay, and had a strong sod with no tendency to springiness in walking over it. It was intersected by innumerable tidal cuts which were filled with water every high tide.

Mr. Smith. EUGENE R. SMITH, Jun. Am. Soc. C. E.—The author made an effort to devise a quick test of the compressibility of the marsh, which might be of use in other tests, for purposes of comparison with this particular tract, in the hope that the information contained in the paper could be more fully utilized by engineers having similar problems to solve, but no satisfactory result was reached and the attempt was abandoned. If any method other than the exercise of the engineer's judgment is perfected at any time which will indicate with some reliability whether a particular tract under investigation is of the character, for instance, of the Hoboken marsh described by Mr. McCann, unreliable in the extent of its compression, or non-compressible, like that described by Mr. Clark, or like that at Islip, which has seemed to be governed to a certain extent by some law, engineers will be pleased to know of it.